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Assessment of SNCR Performance on Large Coal-Fired Utility Boilers [1]

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INTRODUCTION

Regulatory agencies, consultants and utilities (SAIC, 1996; ICAC, 1994) have made assumptions regarding the NO_x reduction capabilities of selective noncatalytic reduction (SNCR) on large coal-fired boilers. Generally, these assumptions are based on the extrapolation of performance data from relatively successful SNCR experience on smaller boilers (<165 MW). However, larger boilers have physical characteristics that may hamper successful SNCR application.

This presentation discusses the results of a program to investigate SNCR performance capabilities on two large pulverized coal-fired boilers. The two units evaluated were Georgia Power Company's Hammond Unit 4, located in Rome, Georgia and Wansley Unit 1, located in Roopville, Georgia. These boilers are examples of units that could be affected by more stringent ozone attainment regulations which would require NO_x controls beyond low-NO_x combustion technologies. Hammond Unit 4 is a wall-fired 500 MW Foster Wheeler unit that has been retrofitted with Foster Wheeler low-NO_x burners and overfire air. This boiler is similar to other Foster Wheeler boilers built during the same period. However, because this unit is equipped with overfire air, its combustion characteristics may not be typical of other Foster Wheeler units equipped only with low-NO_x burners only. Wansley Unit 1 is a twin-furnace, tangentially

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fired 880 MW Combustion Engineering unit that has been retrofitted with ABB C-E Services' Low-NO_x Concentric Firing System Level 2. This unit is typical of other large T-fired boilers of its vintage (supercritical boilers built in the late 60s or early 70s that have been retrofitted with a low-NO_x firing system to comply with Clean Air legislation).

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SELECTIVE NONCATALYTIC REDUCTION

In concept, the SNCR process is simple. Ammonia (anhydrous or aqueous) or urea (aqueous) is injected and mixed into the boiler flue gas in a limited temperature range (1600 to 2100°F). The injected reagent then reacts selectively with NO_x to form N_2 and H_2O. Introducing the reagent at temperatures that are too high can degrade performance because the reducing agent is oxidized and little or no NO_x reduction occurs. Further, at lower temperatures the reduction reactions are too slow and unreacted reagent "slips" through the process. On small coal-fired units (i.e., <165 MW), SNCR has demonstrated NO_x reduction capabilities ranging from 25 to 45 percent under normal load dispatch conditions with tolerable levels of ammonia slip. This variation in NO_x reduction capability depends on site-specific considerations and the amount of ammonia slip that is considered tolerable.

In practical applications, the SNCR process can be complicated. Nonuniformities in velocity and temperature at the reagent injection location can pose operational difficulties because of the inherent sensitivity of the process to these parameters. The physical location of the effective temperature range within the boiler depends on operating factors such as unit load, fuel type, soot blowing cycles, mill patterns, etc. Generally, these factors require the utilization of multiple injection elevations in full-scale systems, especially for boilers operated with a cycling load profile.

For larger boilers (i.e., >300 MW), there are numerous challenges associated with applying SNCR. In particular, the large physical dimensions pose challenges for injecting and mixing the chemical with the flue gas. Another issue with larger units is the fact that the SNCR temperature window often exists within the convective passes. Demonstrations to date at Port Jefferson, Morro Bay and Merrimac have shown that injecting in the convective pass creates high ammonia slip due to limited residence time.

PROGRAM ORGANIZATION AND APPROACH

A three component program was used to assess SNCR performance on the Hammond and Wansley boilers. First, field measurements, including furnace exit gas temperatures and emissions characteristics, were conducted to determine existing performance conditions. Second, physical cold flow models of each boiler were used to assess the mixing characteristics of a number of reagent injection strategies. Finally, computational fluid dynamics (CFD) modeling was utilized to evaluate the most promising injection strategies that were identified during the physical modeling study. The focus of this effort was to assess SNCR performance potential at full load under steady state operating conditions assuming base load operations.

FIELD MEASUREMENTS

Although only full load data were used in this study, temperature and emissions measurements were collected at various loads and operating conditions. At Plant Wansley, data were gathered at loads of 880, 650 and 450 MW. Tests performed at full load (880 MW) showed that furnace exit gas temperatures averaged in excess of 2340°F. Tests were also performed at Plant Hammond Unit 4 at loads of 480, 400 and 300 MW. At full load temperatures measured at the furnace exit averaged 1940°F.

PHYSICAL COLD FLOW MODELING

Physical cold flow modeling was used to screen possible SNCR injection scenarios for both Hammond Unit 4 and Wansley Unit 1, ultimately limiting the number of cases investigated with CFD modeling. Although not capable of simulating temperature effects, physical modeling provided a method for quickly screening the mixing performance of different injection configurations. Velocity and tracer gas measurements were used to quantitatively define mixing performance in the 1:24 scale models. Over 20 configurations were evaluated for the Hammond model, with an additional 15 for the Wansley model.

CFD MODELING

Computational tools used during this program simulate reacting and nonreacting flow of gases and particles, including gaseous diffusion flames, pulverized-coal flames, liquid sprays, reacting two-phase flows and other oxidation/reduction systems. BANFF is Reaction Engineering International's (REI) three-dimensional, gas-phase turbulent reacting flow code. GLACIER adds physical models to treat two-phase flows. These software tools have been applied to a wide variety of industrial systems encompassing utility boilers, gas turbine combustors, rotary kilns, waste incinerators and others.

BANFF and GLACIER are both steady-state three-dimensional CFD codes that fully couple reacting gases, solids and liquids with turbulent mixing and radiative heat transfer. Coupling turbulence and heat transfer with finite-rate reaction chemistry requires the number of chemical kinetic steps to be relatively small. BANFF and GLACIER use assumptions of partial equilibrium and steady state species to compute local finite-rate chemistry using a set of reduced kinetic steps for slow reactions and minimize Gibbs free energy for all other species. A reduced set of seven SNCR reactions is fully coupled into BANFF and GLACIER (Brouwer, et al., 1996). The reduced chemistry is based on the kinetic rates of Miller and Bowman, with recent literature modifications.

RESULTS AND DISCUSSION

The SNCR systems evaluated in this program were designed for full-load steady state operations only. (For example, multiple levels of wall injectors or rotating furnace lances would be required to adequately follow cycling operations and changing boiler conditions.) As a result, caution should be taken in applying these results to day-to-day operations with various boiler duty cycles and swinging loads. In actual boiler operations, the achieved levels of NO_x reduction may be lower than those reported herein.

For the wall-fired unit equipped with low-NO_x burners and overfire air (Hammond 4), eight injection scenarios were evaluated. The results showed that SNCR has the potential to reduce NO_x emissions by up to 30-35 percent while maintaining ammonia slip below 5 ppm. Of the technologies evaluated, the most promising scenario involved the injection of ammonia (NSR=1.0) via a row of high-energy wall injectors located on the front wall 14 feet above the tip of the nose. The improvement in NO_x reduction at higher NSRs was relatively small, further decreasing the already low levels of reagent utilization.

For the tangentially fired unit equipped with a low NO_x concentric firing system (Wansley 1), seven injection scenarios were evaluated. The results showed that SNCR has the potential to reduce NO_x emissions by only 22 percent with an ammonia slip of 6 ppm. The most promising scenario involved the injection of aqueous urea via high-energy wall injectors located on the front wall 29 feet above the tip of the nose. The firing characteristics of this boiler (supercritical, separated overfire air, eastern bituminous fuel, 8 corner) make achieving higher levels of NO_x reduction impractical. The most influential factor is the separated overfire air system, which elevates upper furnace temperatures by causing the combustion process to extend beyond the furnace nose and into the convection section.

For every case evaluated, ammonia slip levels at the model exit were highly variable. Generally, the peak ammonia slip was more than an order of magnitude higher than the average ammonia slip. For example, if the average ammonia slip was 6 ppm, the peak ammonia slip was at least 60 ppm. Although limited to a small region of the total exit area, the impact of such a high ammonia concentration could result in localized pluggage of an annular region of the air heater as it rotates through the high slip zone.